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Evidence for metastable defects in airgap interconnects

C. Guedj [a,*], A. Stich [b], W. Pamler [b], Z. Gabric [b], F. Mondon [a]

[a] CEA-Leti, 17 Rue des Martyrs, 38054 Grenoble Cedex, France
[b] Infineon Technologies AG, Otto-Hahn-Ring, 6, 81739 Munich, Germany

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Abstract

Electrical measurements demonstrate that some metastable defects are present inside airgap interconnect structures realized with the close-off approach. Leakage and capacitance strongly depend on sweep conditions and temperature, which suggests the presence of traps. Compared to homologous full structure, the relative increase of defect states in airgap structures can reach up to ~5000 for 0.6 μm spacing in the Poole-Frenkel regime. TVS spectra also suggests the presence of mobile species like surface states, trapped charges or mobile ions. These defects gradually evolve with electric and thermal stress, therefore they could be reduced by proper post-growth processing steps.

Keywords: Airgap; TVS; Leakage; Ions; Stress; Reliability

1. Introduction

Airgap structures are among the most promising devices to reach the level of performance required by the ITRS roadmap [1] for advanced interconnects, especially in terms of dielectric constant, but the reliability of these structures is a major concern. The local composition, microstructure and electrical properties inside the airgap are likely to play a role in the potential failure mechanisms. The presence of a inner solid–gas interface could induce a broad variety of surface states, depending on the growth scheme. At the moment several papers have addressed the dielectric reliability of airgap interconnects [2–5] but little is known about the specific electrical defectivity of the airgap approach. In this paper, we have evaluated the leakage and capacitance behavior of interconnect structures with airgaps in comparison with structures without air gaps, both built by the same processing scheme. The leakage conduction mechanisms were also studied with an approach similar to the triangular voltage sweep (TVS) method [6], versus temperature and bias stress. We show that some metastable defect species are present inside the airgap devices. These mobile species are sensitive to both thermal and electrical stress.

2. Experimental

The airgap formation using selective ozone/TEOS deposition is detailed in several papers [5,7,8]. The formation of airgap (Fig. 1) and SiO_2 (full) devices with similar geometry on the same wafer is obtained by lithography, which enables a relevant comparison. A strong capacitance reduction is achieved when SiO_2 is replaced by airgap. (Fig. 2), leading to a k_{eff} down to 2.4.

2.1. Electrical measurements

Electrical tests under dry N_2 were performed with a classical meander/comb device after a preventative 120 °C 48 h anneal to remove potential moisture inside the airgaps. The quasi-static leakage and capacitance were obtained with an HP 4156 C parameter analyzer. The TVS-like measurements started with 600 s of stabilization at −1.85 MV/cm. The leakage current measurements above 2 MV/cm were carried out at room temperature by applying a voltage ramp with 60 kV/cm steps and a settling time of 300 s to comb–comb interdigitated structures.

* Corresponding author. Tel.: +33 438789105.
E-mail address: cguedj@cea.fr (C. Guedj).

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Fig. 1. SEM picture of the airgap interconnect.

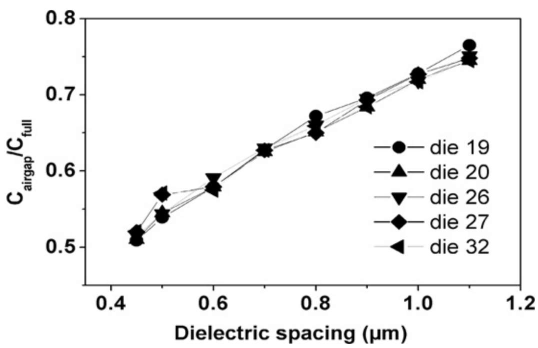

Fig. 2. Capacitance ratio between airgap and analogous SiO_2 interconnects.

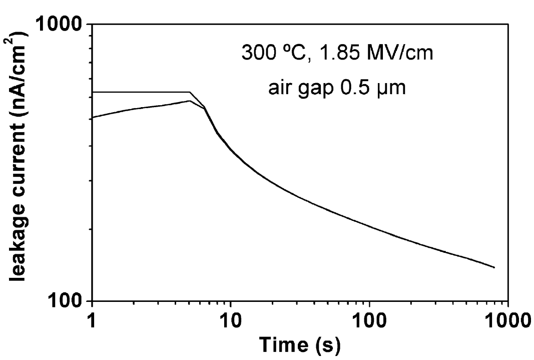

Fig. 3. Typical evolution of leakage current for pristine airgap device stressed at 300 °C and 1.85 MV/cm as a function of settling time. The conventional inverse time dependence typical of relaxation effects is not obtained.

3. Results and discussion

3.1. Thermal evolution of leakage currents and capacitance

A strong dependence of the sweeping conditions is obtained. When a bias is fixed, the stabilization of the leakage is usually slower than the inverse time dependence typically obtained for pure dielectric relaxation effects (Fig. 3). Compared to similar porous ULK devices, the dielectric is slower to reach steady state conditions, which suggests a specific contribution of slow defect species, traps or other defective states. A full frequency-dependence analysis of the dielectric response would be required to check if this time response would be detrimental at normal operating speeds. The $I(V)$ curves strongly depend on the sweep conditions, but at field lower than 2 MV/cm, the leakage currents of airgap samples is usually ~1 order of magnitude higher than the full structure leakage (Fig. 4) for a spacing of 0.5 µm. The peculiar temperature dependence of the leakage current (Figs. 5 and 6) also confirms the presence of traps. The complexity of the time and thermal dependence suggests a possible mixed contribution of 3D leakage in TEOS and internal surface (2D) leakage inside the airgap.

At higher electrical fields, the conduction mechanisms is best described best by the Poole-Frenkel (PF) model above 4.5 MV/cm. In comparison, this conduction mechanism usually occurs above 1 MV/cm in the case of interconnects embedded in a porous ULK matrix [9]. The Schottky conduction model would give unrealistic values for the dielectric constant, therefore it does not apply here. The PF current density is given by

$$J_{\mathrm{PF}} = q\mu N_{\mathrm{t}} E \exp\left(\frac{-q\Phi_{\mathrm{t}}}{k_{\mathrm{B}}T}\right) \exp\left(\frac{\sqrt{qE/\pi\varepsilon_0 k_{\mathrm{pf}}}}{k_{\mathrm{B}}T}\right) \quad (1)$$

where k_{pf} is the dielectric PF constant, μ the charge carrier mobility, Φ_{t} the trap potential well height, k_{B} the Boltzmann constant and N_{t} the density of defect states.

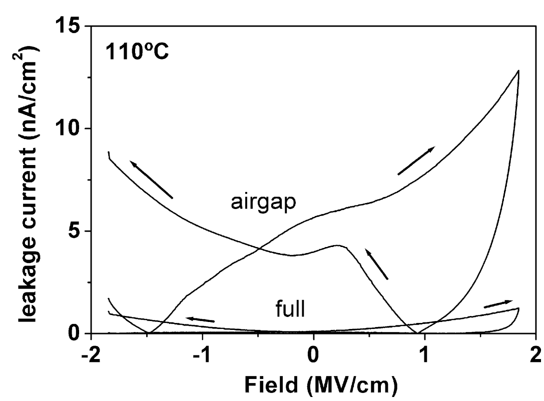

Fig. 4. Comparison between the leakage currents of full versus airgap device with 0.5 µm space at 110 °C. The measurement started with 600 s of stabilization at −1.85 MV/cm to outline the influence of the sweeping conditions.

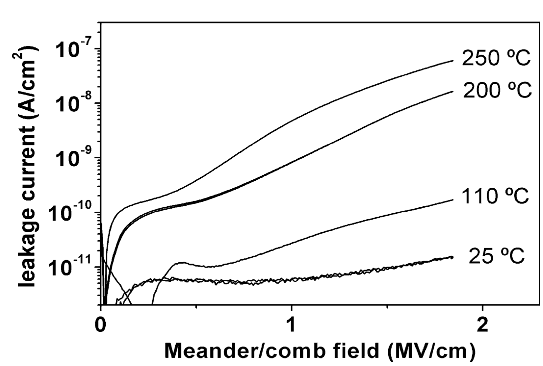

Fig. 5. Typical leakage currents versus field and temperature for air gap devices with 0.5 µm space. The measurement started with 1 min stabilization at 0 V, except for 110 °C.